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# SPATIAL VALIDATION OF COTTON SIMULATION MODEL IN RELATION TO SOILS AND MULTISPECTRAL IMAGERY

**Javed Iqbal and J. Alex Thomasson**
**Department of Agricultural and Biological Engineering**
**Mississippi State University, MS**
**Frank D. Whisler**
**Deptartment of Plant and Soil Science**
**Mississippi State University, MS**
**John J. Read, James M. McKinion, Jeffrey L. Willers, and Johnie N. Jenkins**
**USDA-ARS Crop Science Research Lab**
**Mississippi State, MS**

## Abstract

Field studies were conducted in 1998 and 1999 in Livingston Field at Perthshire Farm, Bolivar County which is located in west-central Mississippi along the Mississippi River. It is a 162 ha field and had a 2-m elevation range. The dominant soil series of the field are Commerce silt loam, Robinsonville sandy loam and Souva loam. The objectives of the study were to 1) compare GOSSYM simulated yield with actual yield, 2) study spatial and temporal pattern of cotton crop across two growing seasons using multispectral imagery, 3) predict field based lint yield from remote sensed data, and determine age of the crop most suitable for aerial image acquisition in predicting yield and / or discriminating differences in cotton growth. Two transects were selected for GOSSYM study, each containing twelve sites. A 1-m length of single row plot was established at each profile. Plant mapping were done five times in 1998 and seven times in 1999 growing seasons. GOSSYM simulation runs were made for each profile and compared with actual crop parameters using root mean square error (RMSE). Results based on averaging common soil mapping units indicate that GOSSYM accuracy in predicting yield varied from 0.45 bales acre$^{-1}$ to 0.61 bales acre$^{-1}$. To monitor and estimate the biophysical condition of the cotton crop, airborne multispectral images were acquired on 10 dates in 1998 and 17 dates in 1999 from April to September. In both years site-specific yield and normalized difference vegetation index (NDVI) were significantly ($p < 0.0001$) correlated in the month of July. NDVI curves of different sites in 1999 showed least distinctiveness due to somewhat wetter weather conditions as compared to drier weather in 1998. Crop growing in or near the drainage areas were low in NDVI and lint yield. Multispectral images acquired between ~ 300 - 600 growing degree days (GDD60) may be useful decision tools for replanting certain areas of the field, especially in dry weather conditions when variability in crop growth pattern is enhanced due to spatial variability in soil texture, which dictates soil moisture holding capacity and its release to plants. Results suggest that 2-3 multispectral images acquired between 800 and 1500 GDD (60) can be used to monitor crop health and predict yield in a normal weather condition.

## Introduction

Precision crop management (PCM) involves more efficient practices that are economical for the producer and beneficial to the environment. The principle is to avoid blanket applications of agrochemicals and instead make site-specific applications in accordance with the needs of soils and crops. Consequently, PCM requires knowledge of how much and when to apply agro-chemicals, site-specifically. There are various methods to determine a site-specific application goal. One method is to use already established calibration curves for an agro-chemical product that has been applied in different soils to achieve optimum yield. A second method is to layout experimental plots at the farm and test different rates of the agro-chemical. Some drawbacks to these approaches are the costs of testing at multiple sites across different years, and the uniqueness of each growing season in determining final yield. An effective and perhaps less costly method is to use a comprehensive, process-level crop simulation model, which considers spatial variability of soils, varietal effects, weather, and all the management inputs on a particular field (Whisler et al., 1986). One can apply "what if" scenarios in a crop model in order to tailor the rate and time of a site-specific application to achieve the yield goal. This will only be possible if each subsystem or module in the crop model is calibrated and validated locally. A drawback to crop models in PCM is the comprehensive amount of data required to either simulate yield or organize in a decision support system. Crop models could be more effective management tools if methods were available to input remote sensing data, which is becoming more cost-effective, reliable and readily available.

Recent developments in high-resolution remotely sensed imagery have increased its usefulness in analyzing spatial and temporal differences in crop growth and development. The objectives of the study were to 1) compare GOSSYM simulated yield with actual lint yield, 2) study spatial and temporal patterns of a cotton crop across two growing seasons using multispectral imagery, 3) predict field based lint yield from remotely sensed data, and 4) determine the age of the crop most suitable for aerial image acquisition in predicting yield and /or discriminating differences in cotton growth.

## Materials and Methods

Field studies were conducted in 1998 and 1999 in the Livingston Field at the Perthshire Farm, Bolivar County, which is located in west-central Mississippi along the Mississippi River. The field has a central-pivot irrigation system and has been cropped continuously to cotton for 45 years. The Livingston Field comprises 162 ha and has a 2-m elevation range (Fig. 2). The dominant soil series are Commerce silt loam (Cc), Robinsonville sandy loam (Ra), and Souva loam (So). In previous studies, we've determined spatial variability of soil physical properties by sampling 209 soil profiles (Fig. 2) to a depth of 1-m based on a 91.4 m grid along 18 parallel transects, with sampling originating from the south-western corner of the field.

### Crop Modeling

The present GOSSYM study only considers two parallel transects, each containing 12 soil sites, located on the west ($T_3$) and east side ($T_{14}$) of the field (Fig.2). These two transects represent about 97 % of the soil-mapping units in the Livingston Field. At each profile, plant measurements were obtained from a 1-m length of a single row. The plant population varied from 10 to 19 plants depending on field location. Plant maps were determined five times in 1998 and seven times in 1999. We executed GOSSYM simulation runs for three different soil hydrology files (scenarios) while keeping all other input variables constant. Deviation of the simulated values from observed values was determined by the root mean square error (RMSE):

$$RMSE = \left[ \frac{1}{n} \sum_{i=n} (y - \hat{y}_i)^2 \right]^{1/2}$$

where $y_i$ are the measured values, $\hat{y}_i$ the GOSSYM predictions, and n is the number of comparisons. Lower RMSE indicates higher accuracy than higher values (Jabro et al. 1994).

The present study used the actual soil hydrology files as input for GOSSYM, but future studies will investigate inputs from (1) averaged soil hydrology files for common soil mapping units and (2) kriged estimates for different soil hydrology files.

### Multispectral Images

To monitor and estimate the biophysical condition of the cotton vegetation, airborne multispectral images were acquired on 10 dates in 1998 and 17 dates in 1999 from April to September. These data were collected by ITD Spectral Visions using an 8-bit real time digital camera system (RDACS) at a spatial ground resolution of 2 meters. Spectral resolution was 10 nm and the three bands were centered at 540 nm (green, chlorophyll reflectance), 695 nm (red, chlorophyll absorption), and 840 nm (near-infrared – NIR tissue reflectance). Image pixel values (digital numbers, DN) were extracted from a 2 by 8 m rectangular area of interest (AOI) centered on each of the 12 GOSSYM sites using ERDAS Imagine Software. The AOI was oriented at an angle of 164 degrees in order to align the pixels of interest with row angle in the field.

The average DN value of each AOI (n=16) was used to study temporal trends in the cotton crop and for derivation of vegetation index. A widely used vegetation index is the normalized difference vegetation index (NDVI). NDVI is an indicator of crop biomass production and canopy vigor:

$$NDVI = \frac{\left(NIR_{840} - R_{695}\right)}{\left(NIR_{840} + R_{695}\right)}$$

The basis of this spectral index is the strong absorption at $R_{695}$ by chlorophyll and low absorption at $NIR_{840}$ by green leaves. As a result, healthy and dense vegetation produces a high NDVI, while less vigorous and sparse vegetation produces a low NDVI.

An Edge detection method was used in ERDAS Imagine software to extract drainage patterns in the field from a bare soil multispectral image collected on April 1, 1999. Next the elevation data was used to model flow accumulation in the drainage areas. This analysis helped to explain different yield patterns in the Livingston Field during wet (1999) and dry (1998) growing seasons (Fig. 1).

## Results and Discussion

### Crop Simulation

Table 1 presents average data based on common soil mapping units from 1999 on NDVI 1500 growing degree days (GDD60), and actual yield, GOSSYM-predicted yield and RMSE. Values for NDVI on July 29, 1999 did not differ ($P > 0.05$) among the three soil series. Actual and simulated yield differed less in the Souva series, but GOSSYM over-estimated yield by 0.3 and 0.4 bales acre$^{-1}$ in Commerce and Robinsonville, respectively. The RMSE values indicate that the GOSSYM accuracy in predicting lint yield varied from 0.45 to 0.61 bales acre$^{-1}$. However, RMSE was inflated by 2-3 by sites located in the drainage areas where actual yield was limited to ~1.0-1.5 bales acre$^{-1}$ by a very low saturated hydraulic conductivity of the soil (Fig. 6a). This is a condition that GOSSYM was unable to accurately simulate and thus predicted yields exceeding 2.0 bales acre$^{-1}$.

**Remote Sensed Data**

Figure 3 presents NDVI values for each profile in Transects 3 and 14 on July 18, 1998 and July 29, 1999, when site-specific lint yield was closely associated with NDVI (Fig. 4). Besides expected profile differences, these NDVI curves clearly illustrate the difference in crop condition between dry and wet years; 1998 received 14.8 inches of rainfall, as compared 23.4 inches in the 1999 growing season (Fig. 1). Decreased NDVI observed in sites 5, 7, and 11 in Transect 3 and 14 in 1998, and in sites 7, and 11 in Transect 14 in 1999, is likely due to their location in the main and tertiary drainage channels where water ponding or soil crusting is evident. Values for NDVI were typically higher in Transect 3 than Transect 14. This is because Transect 3 is mainly comprised of sandy loam soil texture with relatively high saturated hydraulic conductivity, and transect 14 is mainly comprised of silt loam soil texture.

The relative rate (or state) of cotton development and vigor among different sites and across each growing season is represented by plots of site-specific NDVI values vs. GDD60 (Fig. 4 A-D). Because image acquisition was started before the planting date in both years, negative NDVI values were recorded until about 750 GDD in 1999 (~ July 2) (Fig. 4A and 4B) and until about 875 GDD in 1998 (~ June 17) (Figs. 4C and 4D). The NDVI values in 1999 reached a maximum at ~1350 GDD (July 23) and then decreased slightly at 1500 GDD (July 29), when large $R^2$_value (0.65) and slope were recorded for the relationship between NDVI and actual yield across the 24 sites (Fig. 5A). The soil texture in the above case would not make a difference in separating NDVI curves for different sites, providing irrigation and rainfall are adequate for growth. As noted above, sites located in the drainage areas had dramatically low yields in the 1999 growing season. During the comparatively dry 1998 growing season, profile NDVI curves started with negative values as expected, but as the season progressed the 12 sites had distinctive values beyond ~ 250 GDD (May 23). The distinctiveness in NDVI curves for different sites in Transect 3 was more obvious, due to the sandy soil texture, as compared to Transect 14 with a silt loam soil texture. In 1998, NDVI of the sites reached a maximum at ~ 1565 GDD (July 18) when values were correlated significantly with actual yield ($R^2$ = 0.83) (Fig. 5B). As the season progressed, a decreasing trend in NDVI values beyond 1565 GDD was associated with a decreasing trend in $R^2$-values between NDVI and yield. The NDVI curves in Figure 4 illustrate the potential to use remote sensing as a decision making tool early in the season, for instance, to determine which area(s) of the field need re-planting, especially in dry weather conditions like 1998.

Best fit linear regression equations between site-specific NDVI values and machine-harvested yield (e.g., Fig. 5) were used to estimate yield for the Livingston Field (Figs. 6B and 6D) based on multispectral images from July 29, 1999 (Fig. 6A) and July 18, 1998 (Fig. 6C). To show the effects of drainage pattern on the field based yield, the GIS-derived flow accumulation network was superimposed on each map. In both years, plants located in or near the drainage areas had low NDVI values (Fig. 3) and corresponding low yields. These low-lying areas were a source of error in the GOSSYM simulation. Some of this error is due to the characteristically low saturated hydraulic conductivity of soils in these areas and this feature is not readily captured by the model. Future studies need to address this problem.

## References

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Table 1. Average values for NDVI on July 29, 1999 (GDD 1500), actual yield, GOSSYM predicted yield and GOSSYM RMSE for three soil series in transects 3 and 14. The number of sites was 12 for Commerce, 8 for Robinsonville, and 4 for Souva.

| Soil series | NDVI (GDD 1500) | Actual yield | GOSSYM yield | RMSE |
|---|---|---|---|---|
| | ………………..bales acre$^{-1}$ ………..…… | | | |
| Commerce Silt loam (Cc) | 0.595 | 2.136 | 2.425 | 0.612 |
| Robinsonville Sandy loam (Ra) | 0.591 | 1.868 | 2.269 | 0.563 |
| Souva Loam (So) | 0.603 | 2.158 | 2.120 | 0.450 |

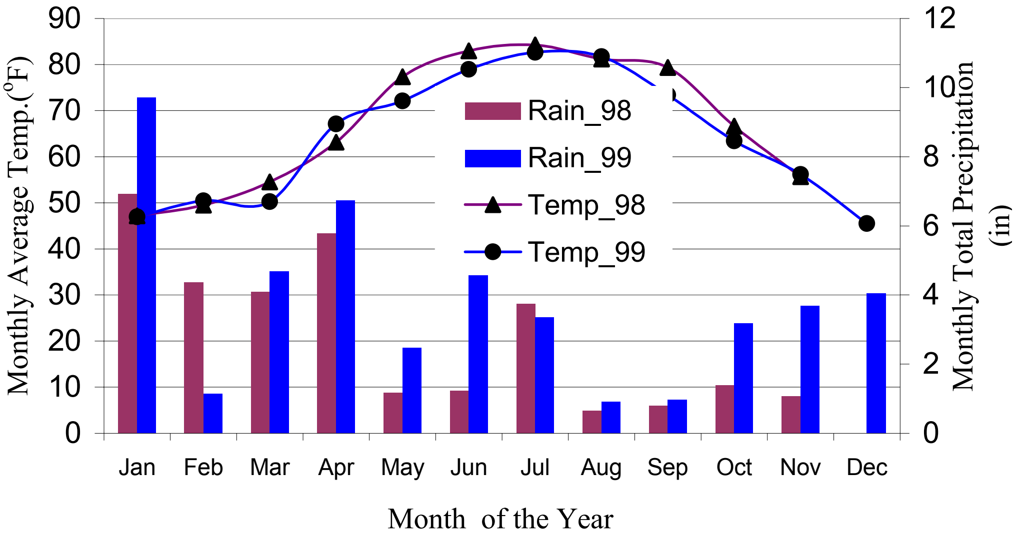


Figure 1. Monthly total precipitation and monthly average temperature during 1998 and 1999.

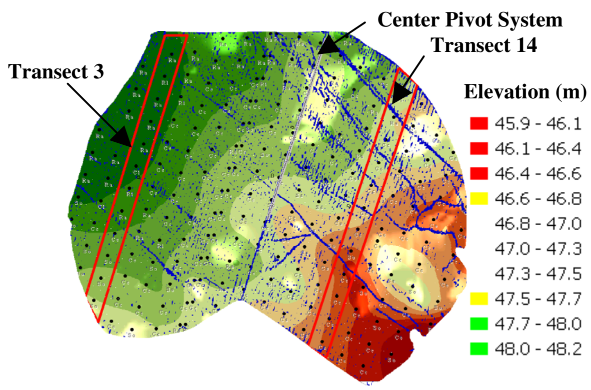


Figure 2. Field elevation, soil mapping units, and flow accumulation patterns in drainage areas.

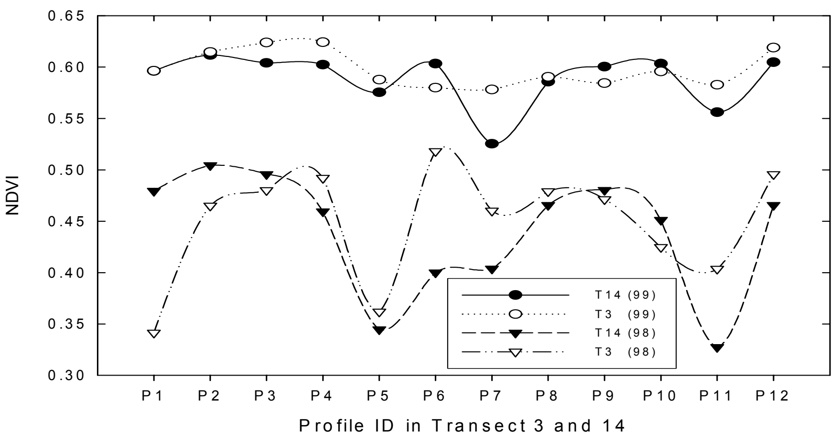


Figure 3. NDVI spatial variability across the sites on July 18, 1998 and July 29, 1999.

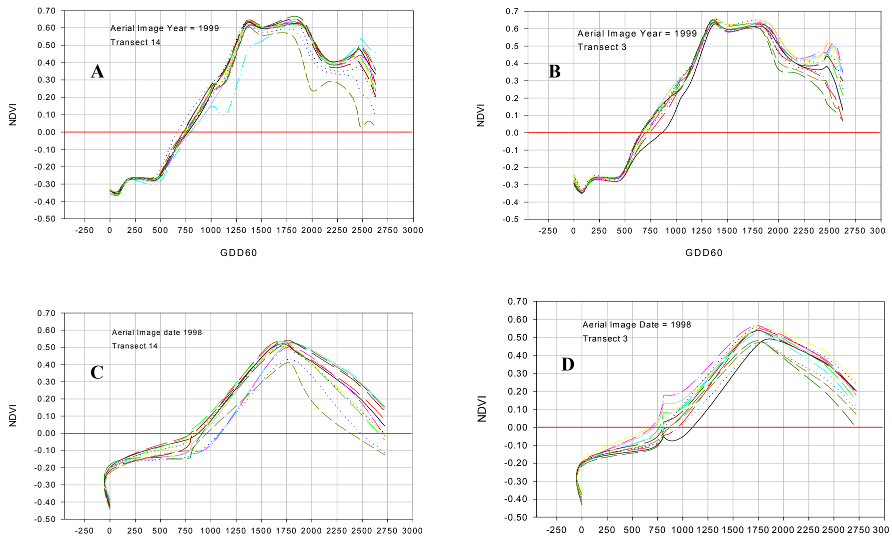


Figure 4. Relationships between NDVI and GDD (60) for each individual site in transect 3 and 14 during 1999 (A, B) and 1998 (C, D).

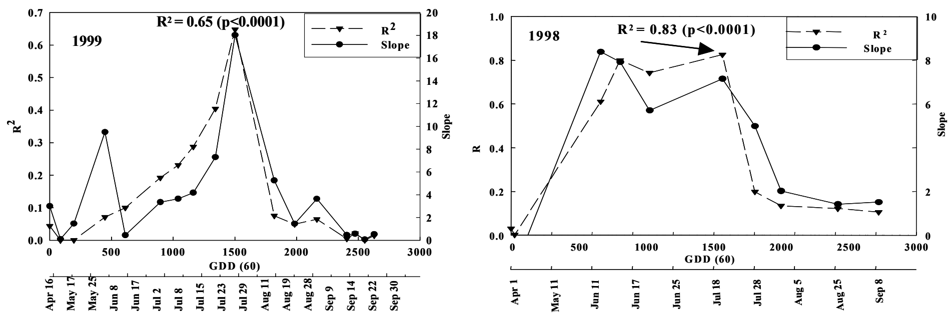


Figure 5. Temporal changes in $R^2$ and slope values for the linear relationship between yield and NDVI in 1999 (n=24) and 1998 (n=12) as a function of GDD(60).

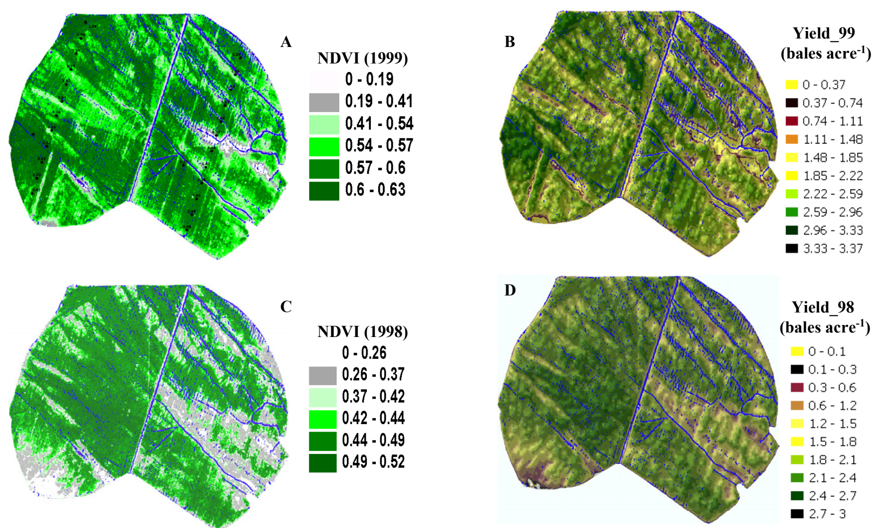


Figure 6. Actual NDVI values and kriged map of cotton lint yield based on NDVI for 1999 (A and B) and 1998 (C and D). The pattern of flow accumulation in the main drainage areas and in low lying areas of the field are also shown in dark blue. Yield monitor values in 1999 for the 24 sites are shown at each point.